Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [A Pattern-Based WBAN System with Bridging Mechanism]
Date Submitted: [March, 2009]
Source: [Kyungsup Kwak[1], Sana Ullah[1], Xizhi An[1], M. A. Ameen[1], Seokho Kim[1], Bumjung Kim[1], Youjin Kim[2], Youngwoo Choi[2], Hyungsoo Lee[2], Jaeyoung Kim[2]]
Company [Inha University[1], Electronics and Telecommunications Research Institute (ETRI)[2]]
Address [428 Hi-Tech, Inha University, 253 Yonghyun-dong, Nam-gu, Incheon, 402-751, Republic of Korea][1], [ETRI, 161 Gajeong-dong, Yuseong-gu, Daejeon, 305-700, Republic of Korea][2]
Voice: [], FAX: [],
E-Mail: [kskwak@inha.ac.kr (other contributors are listed in "Contributors" slides)]
Re: []
Abstract: [We present a Pattern-Based WBAN system that exploits the Pattern Orders (PO) of BAN Nodes (BNs) to accommodate the normal traffic and sends a wakeup radio signal to treat on-demand and emergency traffics. Our system is supported by a sophisticated Bridging function that allows communication between different BNs working on different bands/PHYs.]

Purpose: [To be considered in IEEE 802.15.6]

Contributors

Name	E-mail	Affiliation
Kyungsup Kwak	kskwak@inha.ac.kr	Inha University
Sana Ullah	sanajcs@hotmail.com	Inha University
Xizhi An	anxizhi@inhaian.net	Inha University
M. A. Ameen	m.ameen@hotmail.com	Inha University
Seokho Kim	sylvstar@inhaian.net	Inha University
Bumjung Kim	ufopoint@gmail.com	Inha University
Youjin Kim	youjin@etri.re.kr	ETRI
Youngwoo Choi	ywchoi@etri.re.kr	ETRI
Hyungsoo Lee	hsulee@etri.re.kr	ETRI
Jaeyoung Kim	jyk@etri.re.kr	ETRI

Outlines

- Introduction
- Pattern Order Concept
- Wakeup Radio
- Bridging Function
- Conclusions

Introduction

Introduction

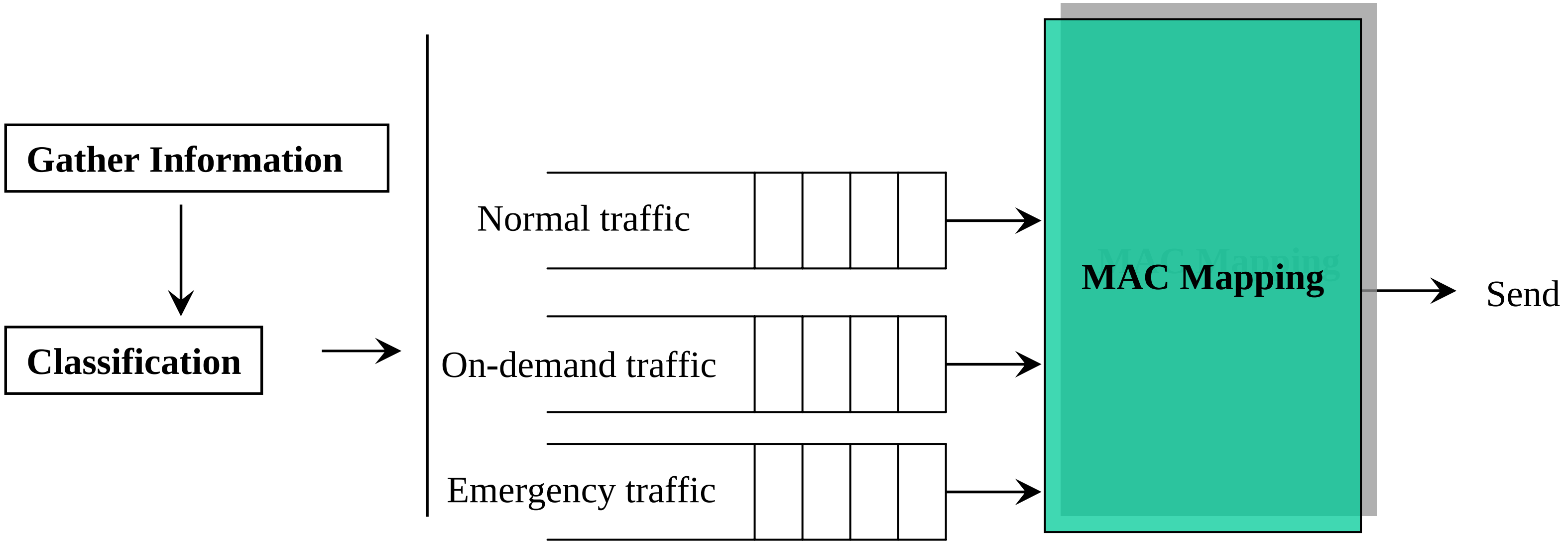
- Energy waste in Sensor Networks
  - Idle Listening
  - Collision
  - Overhearing
  - Over-emitting
  - Others
- Suitable wake-up mechanisms can save significant amount of energy in WBAN and increase the network lifetime.
  - Device wake-ups only when necessary, otherwise it sleeps thereby saving energy.

Radio State	Power Consumption (mW)
Transmit	81
Receive/Idle	30
Sleep	0.003

  - Coordinated and controlled data transmission can reduce energy consumption.

WBAN Traffic Classification

- Data traffic in a WBAN is classified into:
  - **Normal traffic:** Based on normal operation between device and coordinator using a defined patterns.
  - **On-demand traffic:** Initiated by Coordinator to know certain information.
  - **Emergency traffic:** In case of critical condition.



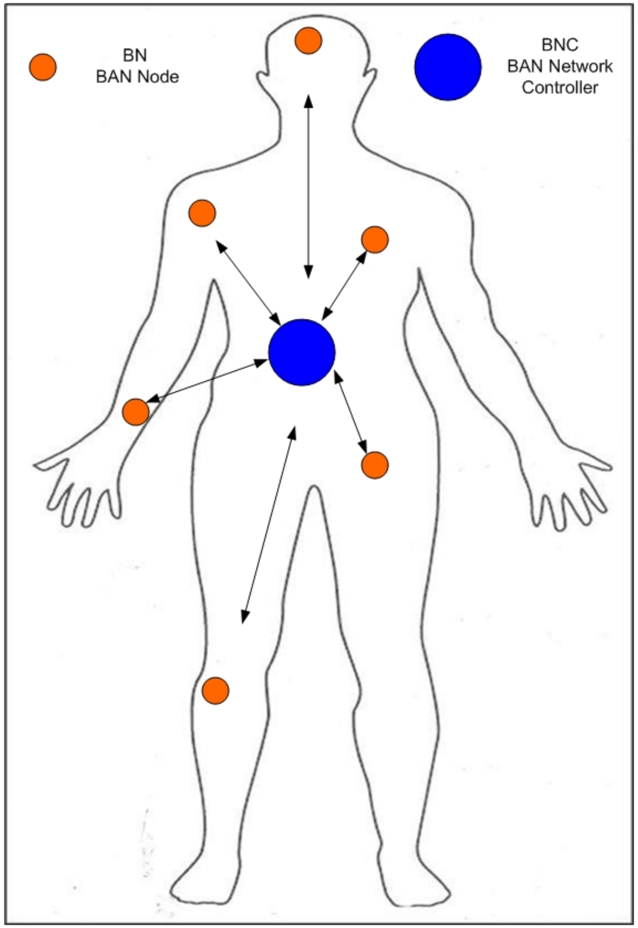
WBAN MAC Issues

- Heterogeneous Traffic
  - Normal, On-demand, and Emergency traffic
- Interoperability
  - Multiple frequency bands and correspondingly multiple PHY techniques
  - Connecting different devices working on different bands/PHYs
- Scalability
  - Variable data rate: Kbps ~ Mbps
  - Variable number of devices
- Energy Saving
  - Synchronous or asynchronous
  - Beacon or preamble
  - Different periods of wake up and sleep

WBAN Characteristics: Traffic & Device

- A network consists of low-power invasive and non-invasive BNs .
- BNs can be
  - **Full functional:** When deal with Multi-Phys.
  - **Reduced functional:** Mostly in the in-body networks.
- One WBAN device is selected as a BNC.
- One-hope coverage range is around 3m.
- The traffic characteristics vary from low to high with periodic and non-periodic intervals, and vice versa.
- The dynamic natures of BNs does not urge synchronized periodic wake-up periods

- Communication flows:
  - Normal Traffic:
    - BNs ⟷ BNC
  - Emergency Traffic:
    - BNs ⟷ BNC
  - On-Demand Traffic:
    - BNC ⟷ BNs
    - BNs ⟷ BNs



Features of WBAN Devices

- BNC: BAN Network Coordinator
  - On AC power supply
    - It can wake-up all the time.
    - It can support normal, emergency, and on-demand traffics.
  - On battery power supply
    - It has certain limitations and should adopt low-power scavenging techniques.
    - It should calculates its own wakeup pattern based on the BN's wake-up patterns.
    - It should maintain the pattern-based wake-up table.
- BN: BAN Node (Device)
  - They are operating on limited power and support a default normal wake-up state.
    - Wake-up and sleep according to pattern-based wake-up table.
    - BN wake-ups upon receiving an 'on demand' request from a BNC.
    - BN wakes-up by itself to handle emergency events.

Typical Settings of WBAN Devices

Device	Freq. Band	Data Rate	Power Supply	Function
Out-Body Device	Unlicensed ISM/UWB Band	High	High-Capacity Battery	Monitoring, Multimedia
On-Body (wearable) Device	Unlicensed ISM/UWB Band or Licensed Medical Band*	Medium	High / Moderate Battery	Monitoring, Connecting implant node and out-body node
In-Body (implant) Device	Licensed Medical Band*	Low	Limited Battery	Medical, Monitoring

* Medical band: MICS, WMRS, WMTS

Device Classification by Function

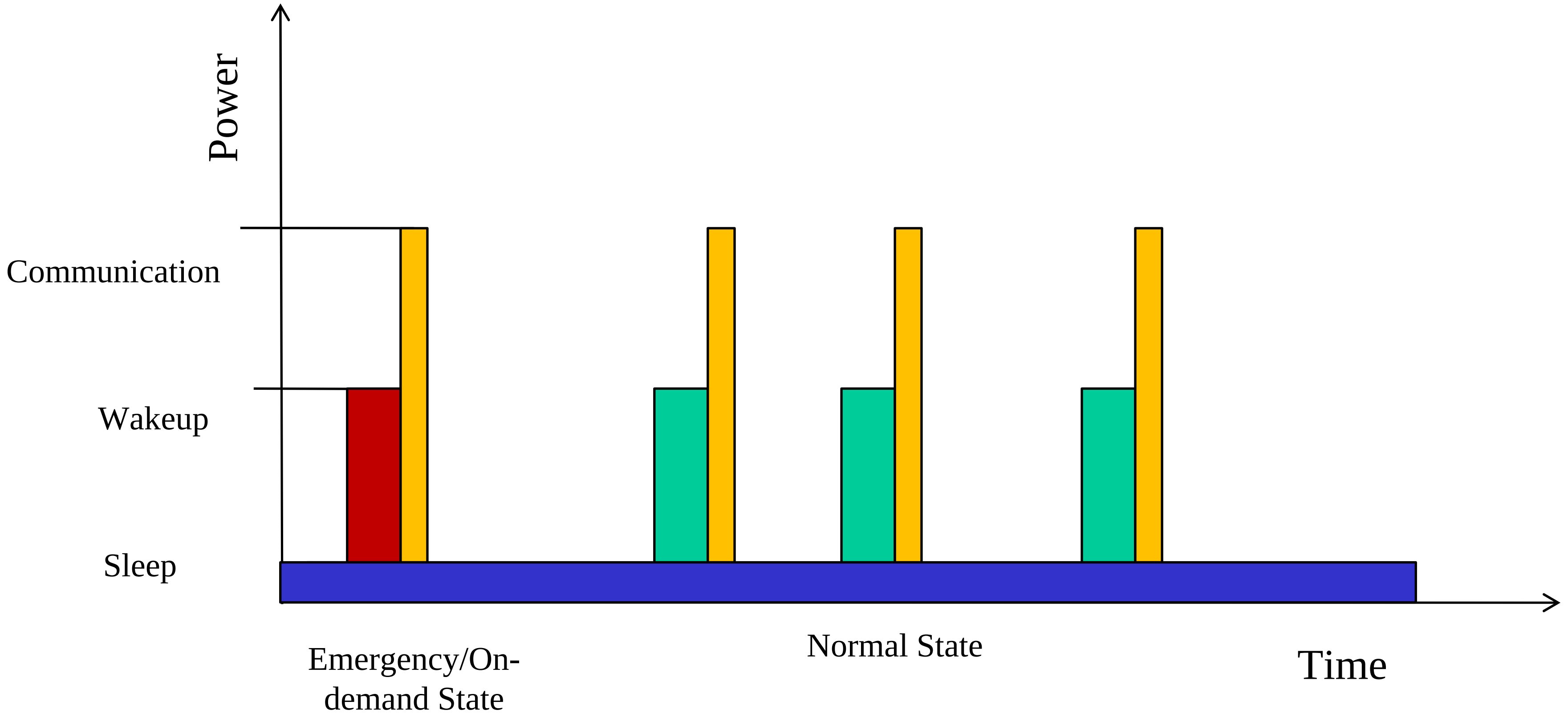
- Full Function Device (FFD)
  - Beaconing function
  - Bridging function
    - Have Multiple PHYs
  - Control functions
  - Generally, it can act as a BNC.

- Reduced Function Device (RFD)
  - Only support one band / one PHY for a specific application
  - Often in-body device due to very limited power and capacity

Wake-up States (1)

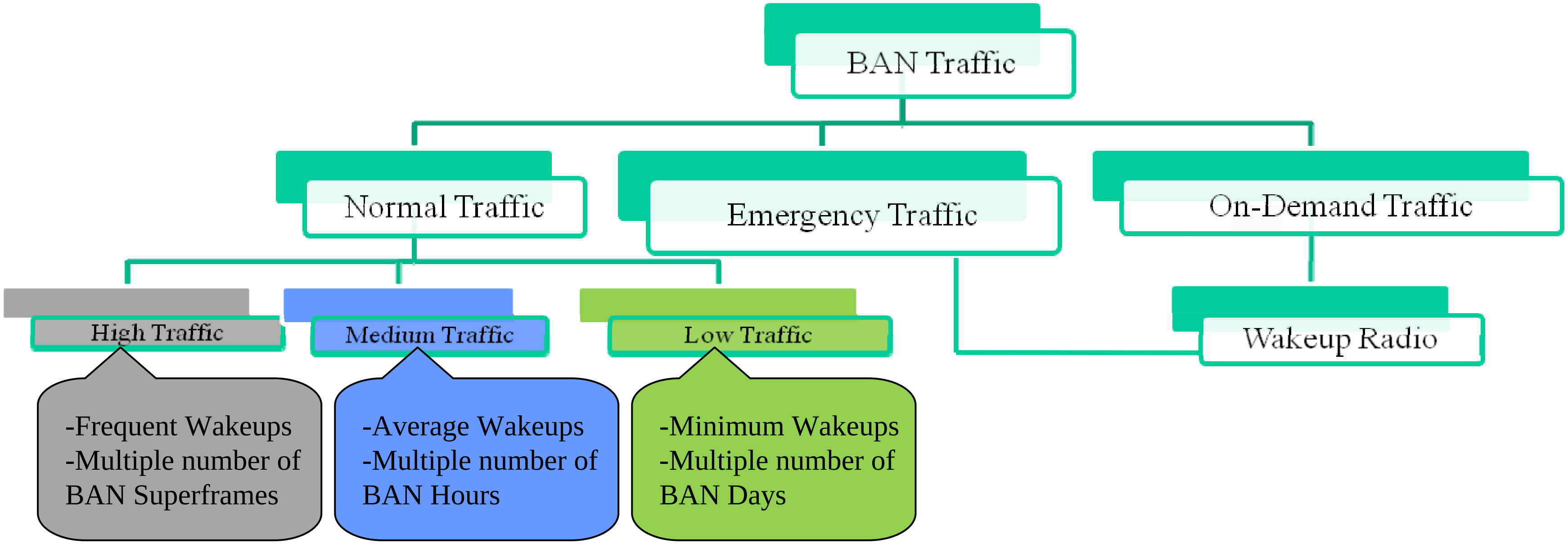
- Sleep State:
  - Default state of BNs.
- Wake-up State:
  - Normal Wake-up State
    - Based on the pattern orders maintained by the BNC.
  - On-demand Wake-up State
    - To handle on-demand requests.
    - BNC can wake up any BN with an on-demand request instead of waiting for its wake-up pattern.
  - Emergency (Self) Wake-up State
    - To handle time critical events
- Communication State
  - Data communication between BNs and BNC.

Wakeup States (2)



Pattern Order Concept

Traffic Levels



High Traffic Wakeup Pattern= *aBANBaseSuperframeDuration* $\times 2^{SO+PO}$ for PO=x

Medium Traffic Wakeup Pattern= *aBANBaseSuperframeDuration* $\times 2^{SO+PO}$ for PO=y

Low Traffic Wakeup Pattern= *aBANBaseSuperframeDuration* $\times 2^{SO+PO}$ for PO=z

Pattern Order (PO)

- Like the SO and BO, a Pattern Order (PO) is introduced.
- The PO adjusts the wakeup patterns of BNs.
- The BNC can change the traffic levels from Low to High by simply changing the values of PO from maximum to minimum.
- The wakeup patterns are calculated by multiplying the *aBANsuperframeDuration* and 2^{PO} where PO is the pattern order.
- For example
  - A BN needs to wakeup after two *aBANsuperframeDuration*
  - The wakeup pattern can be calculated as

Wakeup Pattern (BN) = $aBANBaseSuperframeDuration \times 2^{SO+PO}$ *symbols Where PO=1*

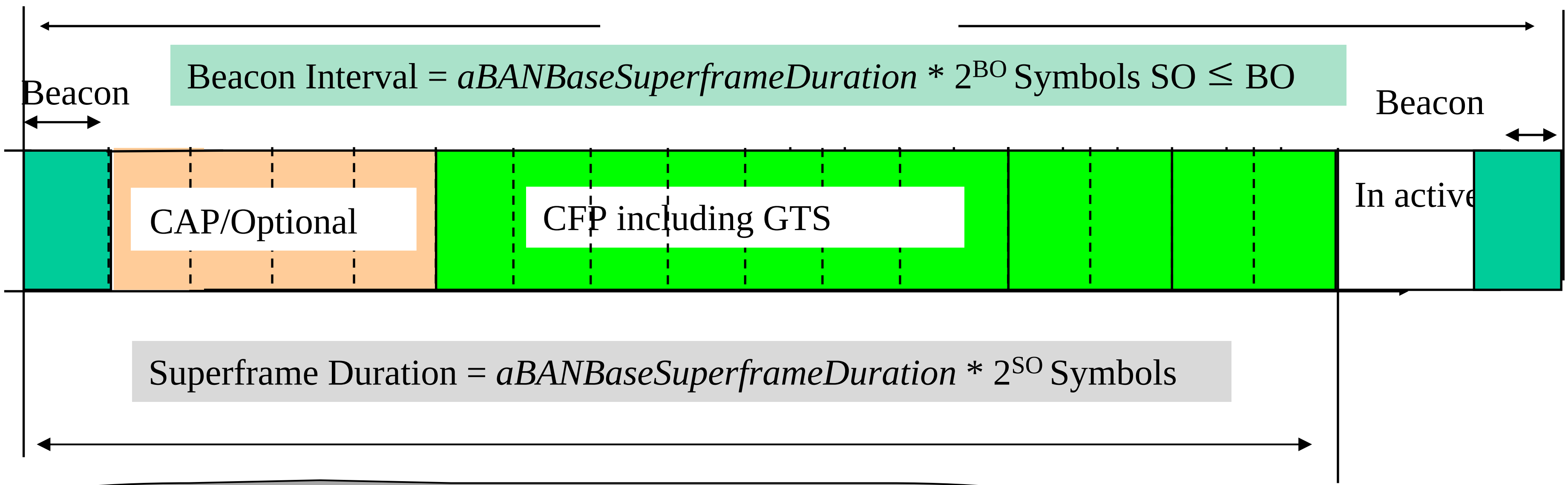
Wakeup Pattern (BN) = $5120 \times 2 = 10240$ μs

Priority-Based Wakeup Patterns

BAN Nodes	Levels	Pattern Order	Wakeup Orders	Priorities
BN(1)	High	PO = x	$aBANBaseSuperframeDuration \times 2^{SO+PO}$	H
BN(2)	Med	PO = y	$aBANBaseSuperframeDuration \times 2^{SO+PO}$	M
BN(3)	Low	PO = z	$aBANBaseSuperframeDuration \times 2^{SO+PO}$	L

Priorities	Levels	BAN Nodes
High	High	BN (1)
Medium	Medium	BN(2)
Low	Low	BN (3)

BAN Superframe and Pattern Order



Pattern-based wakeup table update: Two approaches
- Use the optional CAP period
- Use wakeup radio

Wakeup Pattern (BN) = *aBANBaseSuperframeDuration* $\times 2^{SO+PO}$ *symbols Where PO=N*

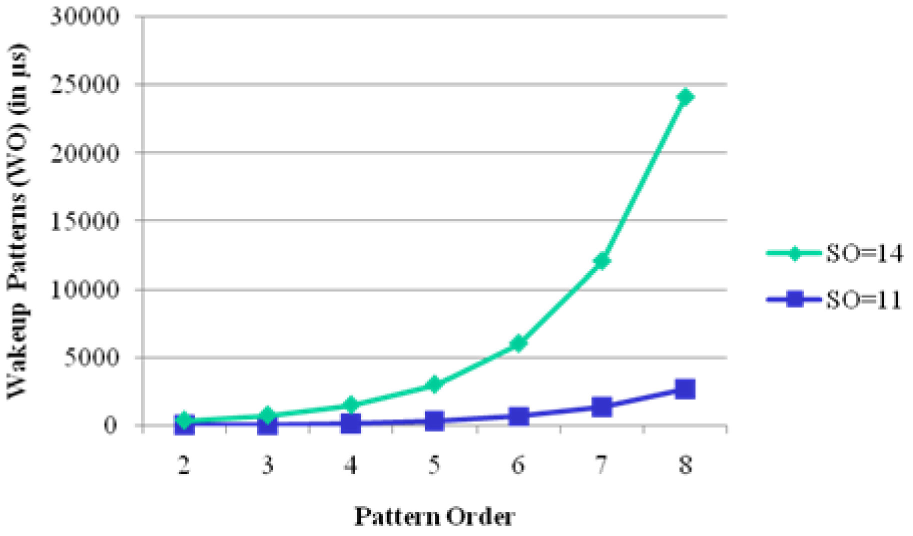
The BANsuperframe duration should be minimum to ensure frequent wakeups in case of high traffic.

Optimum Pattern Orders

- The calculation of an optimum pattern orders for a BN depends on the application requirement.
- In the following table, SO=11, and the aBANSuperframe duration is 10 seconds, each hour has 343 frames.

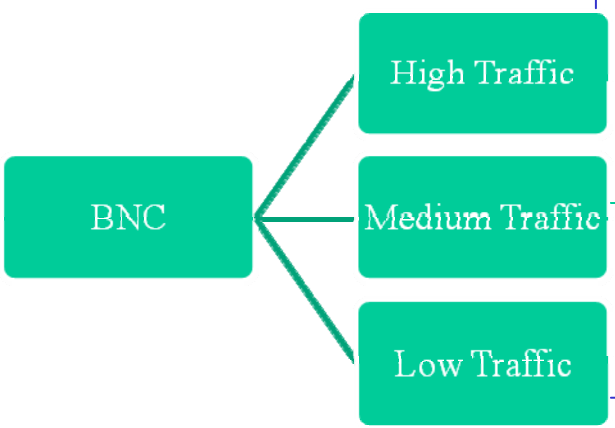
BAN Nodes (BNs)	Wakeup Description	Pattern Orders (PO)	Wakeup Orders (WO)
Insulin Sensor	6 Times in a BAN Day	6	$= aBANBaseSuperframeDuration \times 2^{SO+6}$
Blood Pressure Sensor	24 Times in BAN Day	8	$= aBANBaseSuperframeDuration \times 2^{SO+8}$
Pacemaker	3 Times in a BAN Day	12	$= aBANBaseSuperframeDuration \times 2^{SO+12}$
Endoscope Capsule	5 Times in a BAN Hour	2	$= aBANBaseSuperframeDuration \times 2^{SO+2}$
Electromyogram (EMG)	1 Time in a BAN Day	14	$= aBANBaseSuperframeDuration \times 2^{SO+14}$
Electroencephalogram (EEG)	10 Times in BAN Day	7	$= aBANBaseSuperframeDuration \times 2^{SO+7}$

Pattern Order Vs Wakeup Patterns



Exponential increase – Maximum POs guarantee long wakeup cycles

Pattern-Based Wakeup Table at BNC



BNs ID	PO	Priorities
Insulin Sensor (ID-1)	6	M
Endoscope Capsule (ID-2)	2	H
EEG (ID-3)	7	L

BNs ID	PO	Priorities
BP (ID-4)	*8*	H

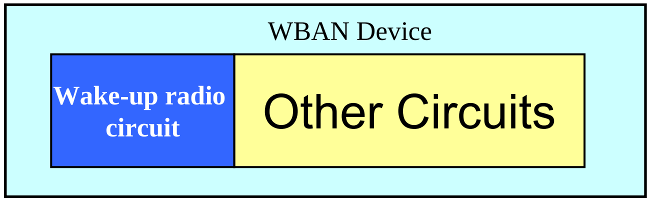
BNs ID	PO	Priorities
Pacemaker (ID-5)	12	M
EMG (ID-6)	14	L

The BNC uses PO to change the traffic levels and to calculate the BNs wakeup patterns.

Wakeup Radio Concept

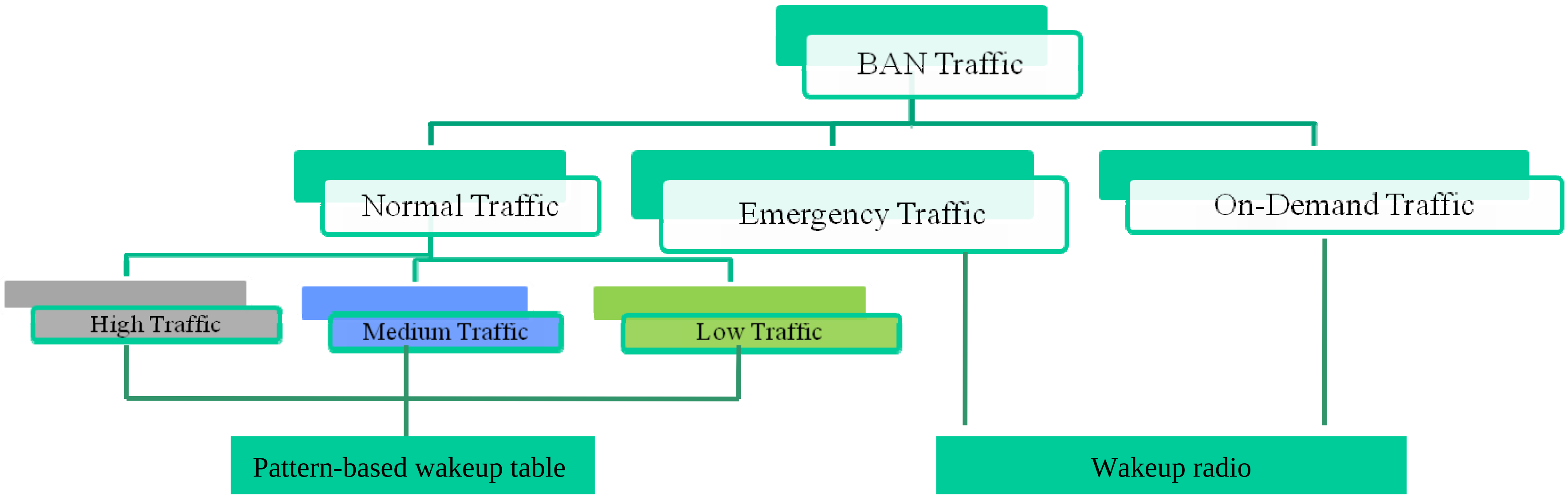
Wake-up Radio Concept

- Wake-up Radio Concept
  - Radio-triggered hardware component in sensor devices.
  - Wake-up radio signal contains enough energy to trigger a wake-up process.
  - Wake-up radio can be adopted in a WBAN.



- Communication channels
  - **Primary channel**: for sending data and control packets.
  - **Wakeup channel**: To wake-up WBAN devices.
- Energy Consumption
  - Energy consumed by wake-up circuit is very low due to simplicity of the circuit design.
- Implementation & Cost
  - Hardware implementation is possible with low cost.

Traffic Levels



	Normal Traffic	On-demand Traffic	Emergency Traffic
BNs(BAN Nodes)	Send data based on the Pattern-based Wake-up Table	Receives a Wake-up Radio from the BNC and respond (MICS)	BNs are triggered when exceeds a predefined threshold and Send a Wake-up Radio (MICS)
BNC(BAN Network Controller)	Send data based on the Pattern-based Wake-up Table	Send a wake-up Radio to BNs (MICS)	Receives a Wake-up Radio and respond (MICS)

Communication Scenarios: Emergency/On-demand

- Emergency (Self) Wake-up:
  - A BN triggers itself to wake-up.
  - BN sends a wake-up signal to the BNC and waits for ACK from the BNC.
  - BNC sends ACK to the BN.
  - BN sends the data.
  - Communication ends when BN receives ACK from the BNC.

- On-demand Wake-up:
  - BNC needs data from the BNs.
  - BNC sends a wake-up signal to the BN and waits for ACK.
  - The BN wakes up and sends ACK.
  - BNC request for data.
  - BN sends data to BNC
  - Communication ends when BN receives ACK from the BNC.

Wake-up Radio: Approaches

- **Unicast wake-up** tone
  - **Directed wake-up** using multiple frequency support
  - Hardware costs for using multiple frequency support is fairly low.
  - Unique frequency can be used by subdividing and allocating to all the BNs.
- **Broadcast wake-up** tone
  - This wakes up all the devices or BNs.
  - Using packet filtration method, a node can decode and know if it is the intended receiver or not.
- **Multicast wake-up** tone
  - This wakes up a group of devices or BNs.
  - BNs can be divided according to priority of data communication or as per traffic level [high, medium and low].

Wake-up Radio: Security

- Wireless media using free bands is unsecure
- Anyone can send signal from outside and wake-up device
- Solution:

1. Using packet filtering method.
   - Wake-up signal in the form of packets containing encrypted data with receiver node’s id.
   - BNs can use filtration method to check the intended receiver.
   - This may result in extra energy cost.
2. Out of MICS band.
3. Using biometric methods
   - Biometrics methods such as fingerprint recognition, iris scan, and voice recognition can be used to authenticate the status of outside users.
   - Can provide overall system security.
   - Needs extra hardware implementation.

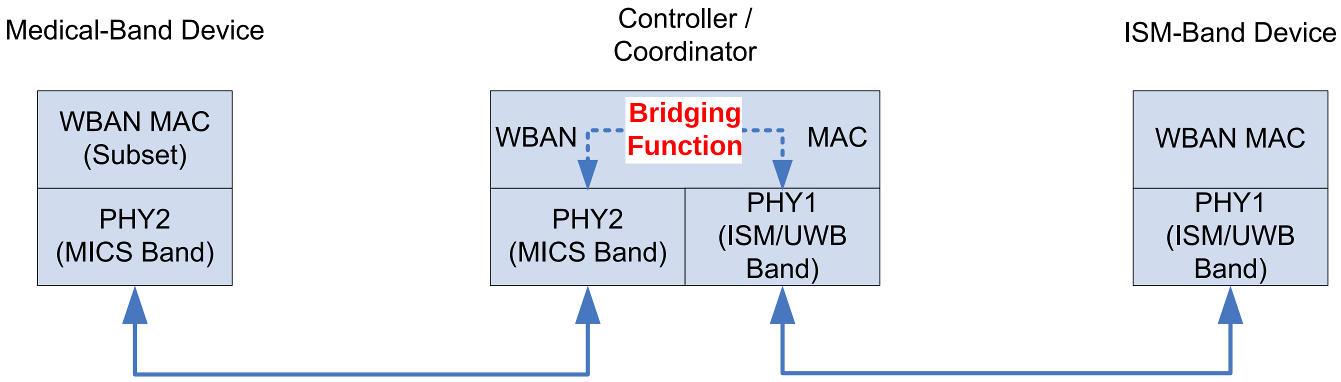
Bridging Function

"One MAC" with Multiple Bands/PHYs

- Multiple Bands, Multiple PHYs
  - For MICS, ISM and UWB bands, each respectively may have its own suitable PHY technique.
  - One such combination of Band and PHY can be regarded as a "Channel" from the viewpoint of MAC.
  - Devices with the same Band and PHY specifications share the same Channel by using some MAC scheme.
- "One MAC": A Common Hybrid MAC Framework
  - Different Channels may adopt one common MAC framework.
    - One Channel is corresponding to one MAC entity.
    - The basic structure of all MAC entities is the same.
    - The MAC entity of one Channel could have minor adjustments (different values of parameters) within this framework to meet its specific requirements.
  - Hybrid Multiple Access Methods within Superframe
    - Beacon Period + Resource Allocation Period + Contention Access Period + Contention Free Period + Inactive Period

Bridging Function

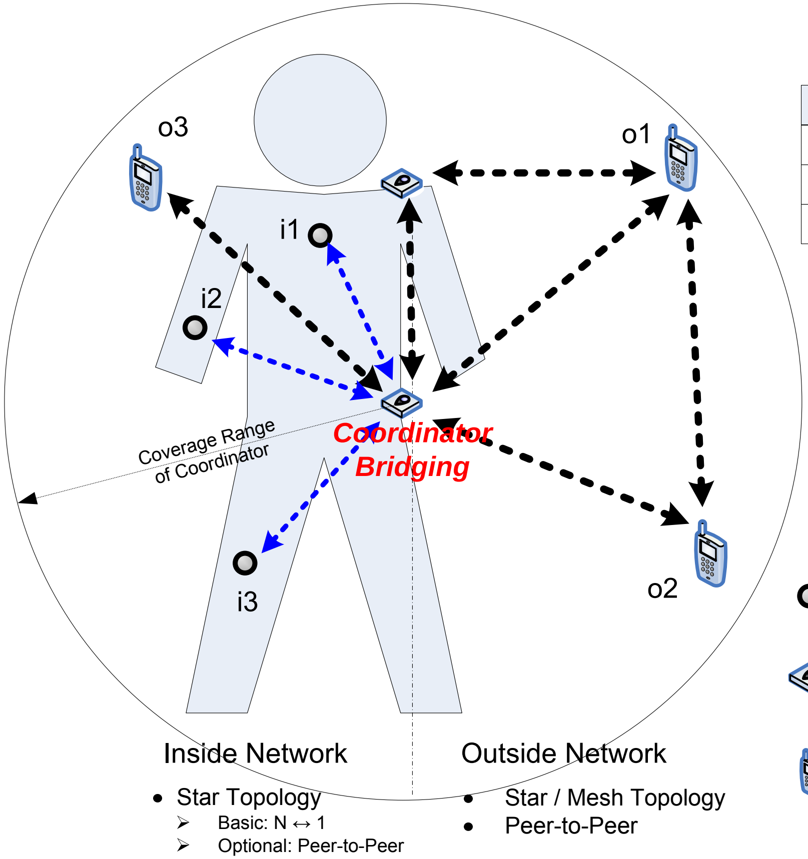
- The Bridging Function connects two or more Channels by forwarding frames between them.
  - MAC transparency: support multiple PHYs
    - Setup logic connections across Channels and among devices with different PHYs.
    - Let all devices see each other as if they are of the same kind.
  - Link-layer MAC Frame (or MPDU) Relay
    - Store (data from one channel) and then forward (data to another channel)
  - Example Protocol Stack of Bridging Function



Bridging Function in Detail

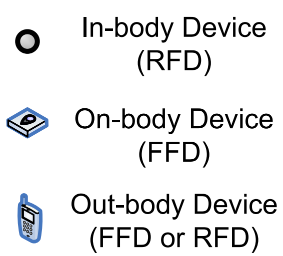
- The node implementing bridging function (in short, bridge) has two or more physical (radio) interfaces.
  - A bridge receives frames from one Channel, review the MAC address of the frame to determine if it should be forwarded to the other Channel(s) it is connected to, and retransmits the frame following the standard protocol rules for the systems it is connected to.
  - Frame Processing: integrity check, frame address filtering and mapping, encrypt/decrypt, physical layer header conversion
- A bridge has enough memory that allows it to store and forward frames between Channels.
- A bridge contains a frame address-forwarding table that it uses to determine if the frames should be forwarded between Channels.
  - Manually configurable
  - Self-learned: bridge monitors the frame traffic in the network to continually update its frame-forwarding table.
- Bridges primarily operate at the physical layer and link layers of the OSI reference model.

WBAN Scenario with Bridging Function



Forwarding Table

in	out
i1	o1
i2	o2
i3	o3



Notes

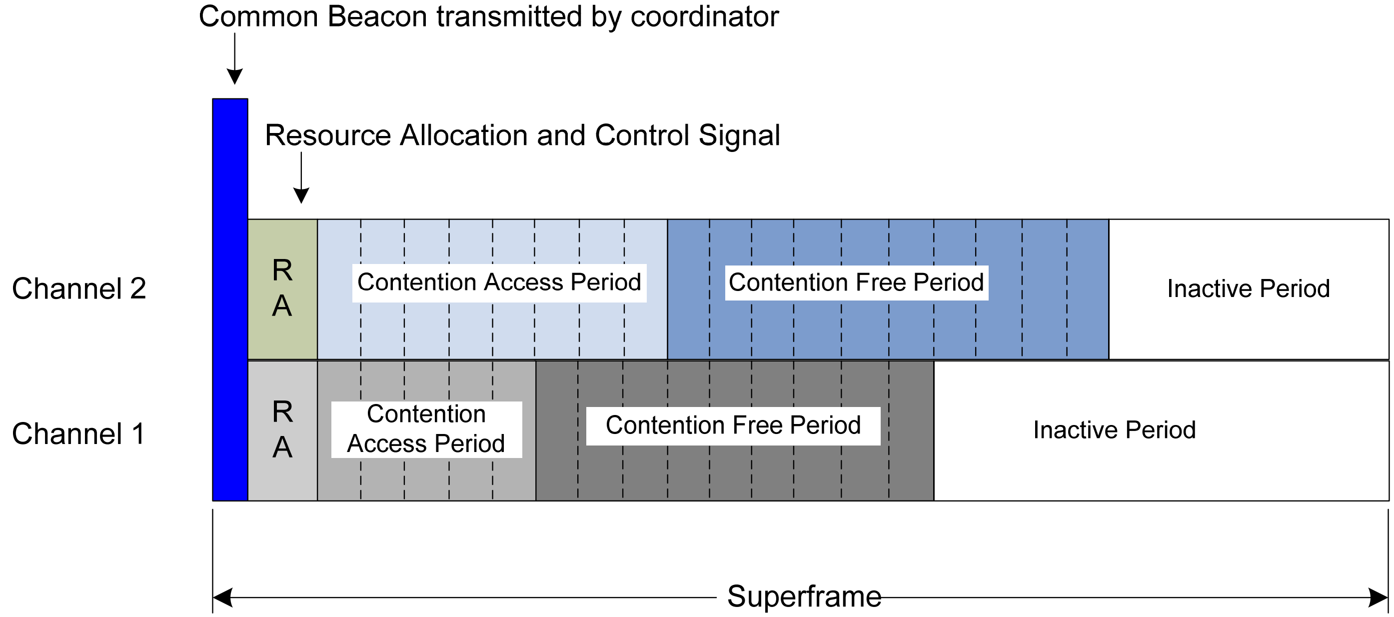
1. A controller can be elected among devices, to work as, i.e., a coordinator (BNC).
2. Bridging is a part of on-body device or out-body device that has multiple PHYs.
3. In-body devices within the coverage range of bridging node can communicate with outside network.

Scheme 1: One Comprehensive MAC

- One MAC
  - Common Beacon
    - The BNC that can support multiple PHY’s broadcasts common beacon on all channels.
    - Provide universal timing/synchronization among all channels.
  - Each channel has suitable media access method.
    - Resource Allocation
      - e.g. Scheduled Resource Allocation, Open Resource Allocation, Contention Resource Allocation
    - Contention Access Period
      - e.g. CSMA/CA, Aloha
    - Contention Free Period
      - e.g. TDMA
    - Inactive Period
      - Sleeping to save energy
- Bridging Function
  - Setup connection across channels.
  - Mapping: let device see all the others as if they are in the same channel.

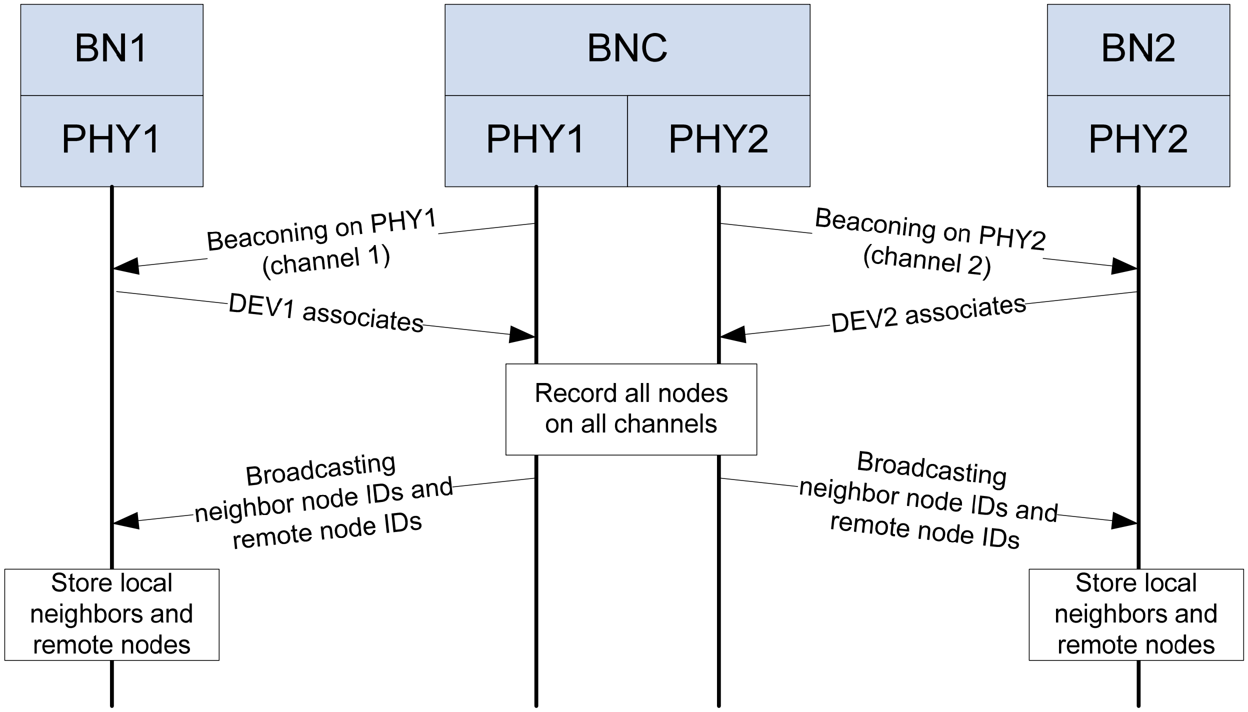
Scheme 1: One Comprehensive MAC

- Hybrid Multiple Access
  - Among channels: Common Beacon and Timing + Bridging Function
  - Within each channel: TDMA, CSMA, Aloha, slotted-Aloha, *etc*.



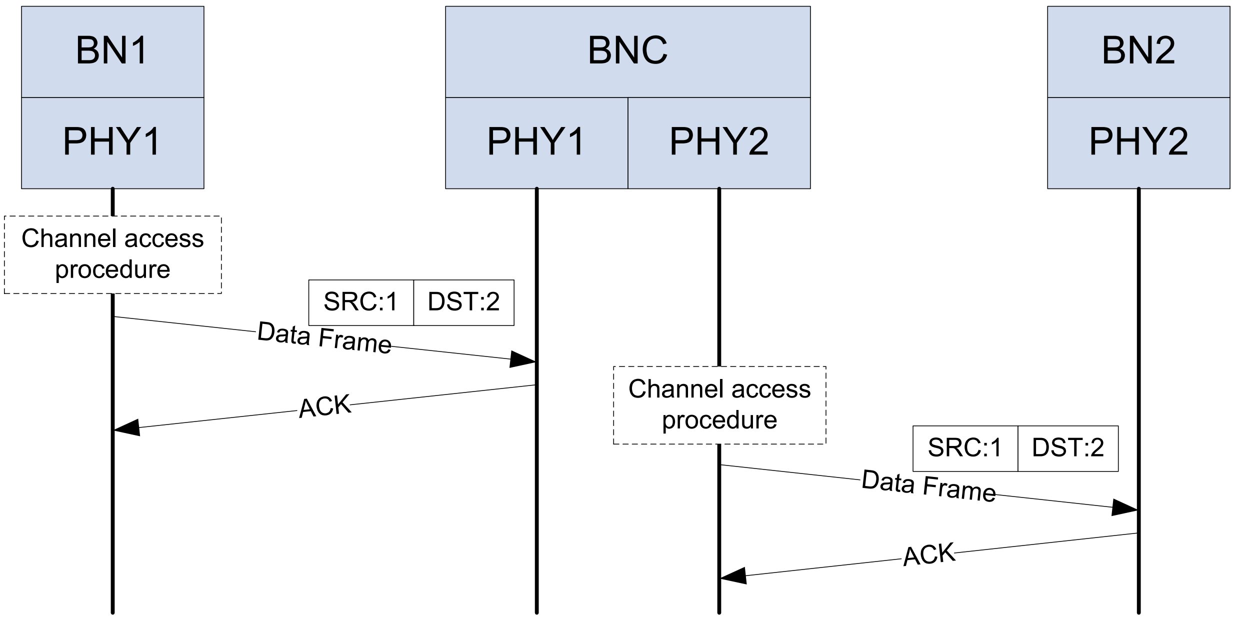
Bridging Function Flowchart: Initialization

- Initialization



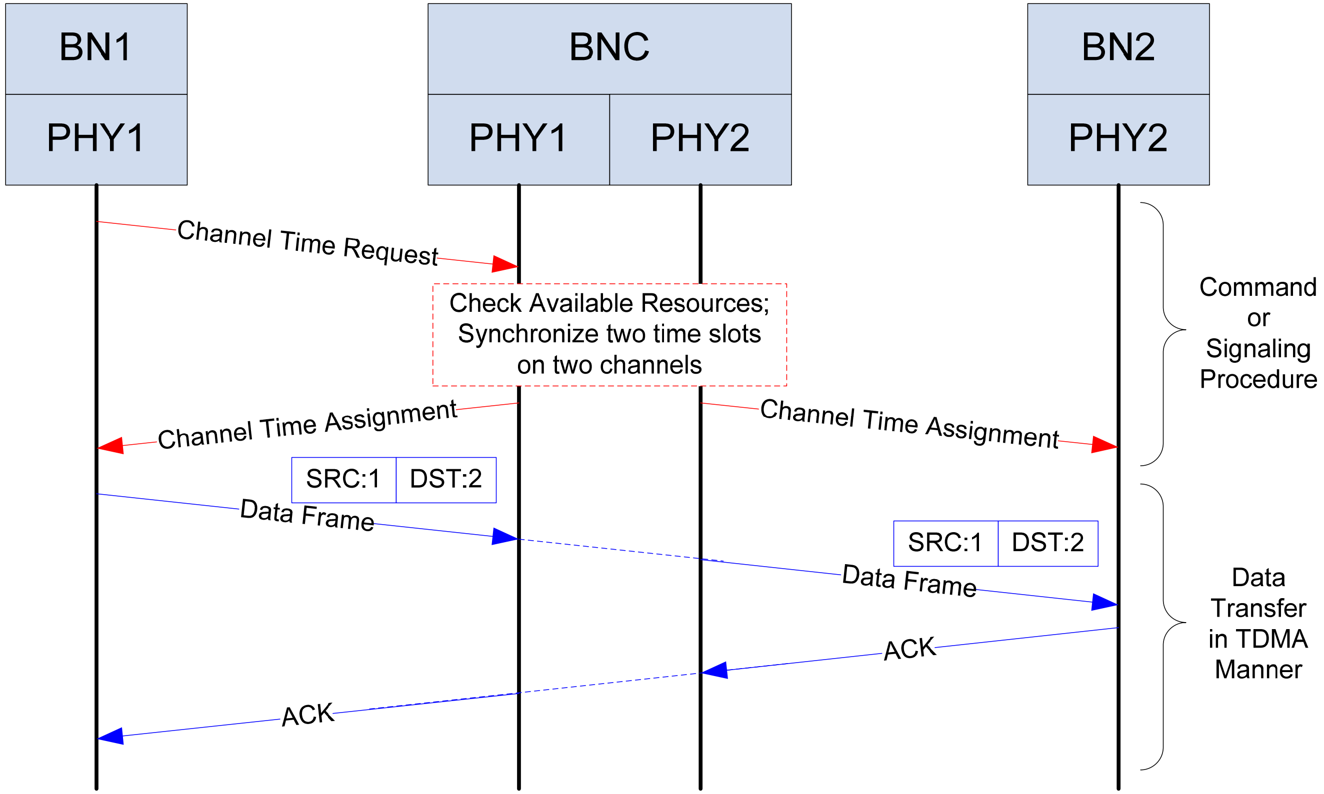
Bridging Function Flowchart: Non-real-time

- Data transfer – Best effort



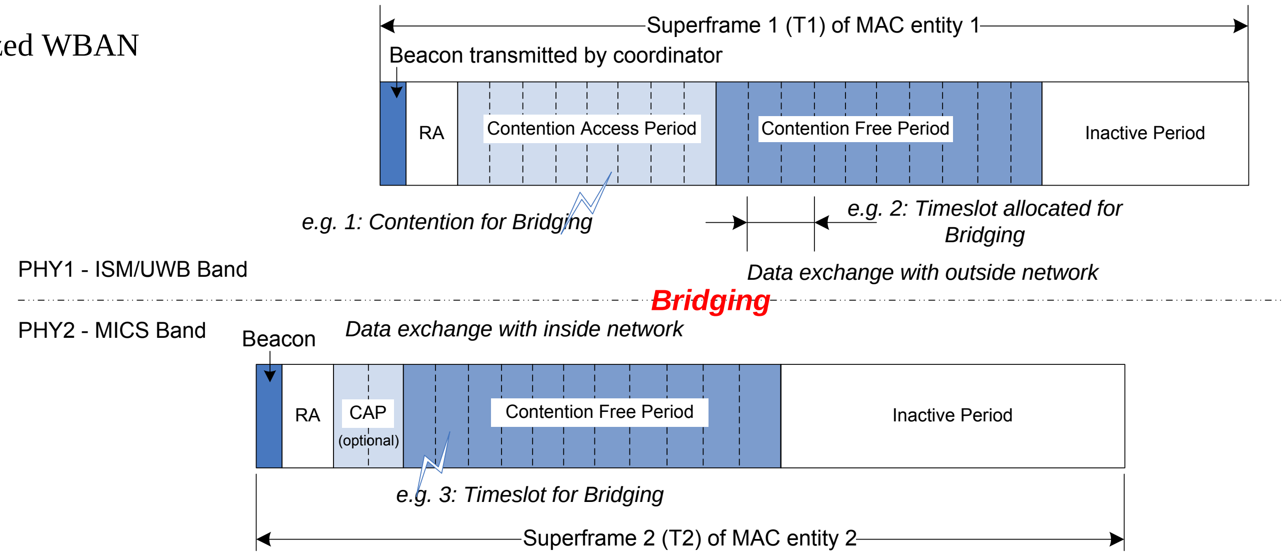
Bridging Function Flowchart: Real-time

- Data transfer – Real-Time



Scheme 2: Two Independent Superframes

- Synchronized WBAN



- The network of ISM/UWB devices has superframe 1.
  - Timeslot for Bridging may have the highest priority.
- The network of MICS devices has superframe 2.
  - T2 may be a multiple of T1.
  - Different wake up and sleeping period.
- Bridging function works in a store-and-then-forward manner.
  - The device doing bridging function belongs to both networks at the same time.
  - In each network, the bridging device can obey current MAC settings of that network, independent of another network.

Bridging function: Discussion

- Advantages
  - Bridging function is useful, especially for in-body devices.
    - It can collect or dissipate data from or to (low-rate) in-body devices in a whole so that the transmission efficiency can be higher.
    - In-body devices can have longer sleeping period, so energy is saved.
    - The design of BN can be simplified.
  - Devices working on different bands/PHYs can transmit simultaneously.
    - Interconnection between different devices is realized logically in MAC.
    - Bridging function makes PHYs transparent to MAC.
- Questions and Answers
  - Does it result in larger delay?
    - Ans.: The extra delay could be controlled in a tolerable range.
  - Is it more complex?
    - Ans.: Interconnection problem itself is very complex. WBAN shall cooperate with existing (medical) devices working on different bands, so this design of one MAC over multiple PHYs becomes reasonable.
  - Is it necessary or not?
    - Ans.: Direct communication between in-body devices and out-body devices may encounter extremely high path loss (low transmission power may even worsen the situation) and the low data rate of in-body devices may slow down the whole network throughput.

Conclusions

Conclusions

- We proposed a pattern-based WBAN system that exploits the pattern orders of BNs to accommodate the normal WBAN traffic.
- The BNC uses PO to calculate the wakeup patterns and to adjust the traffic levels.
- The wakeup radio concept treats on-demand and emergency traffic in a reliable manner.
  - Why not use it for normal traffic?
  - Wakeup radio vs. Pattern-based wakeup for normal traffic.
- We further introduced a bridging function that allows communication between different devices working on different bands/PHYs.
- Future work includes:
  - We will consider the performance criteria.
  - Working on a PHY proposal for May 2009 meeting.